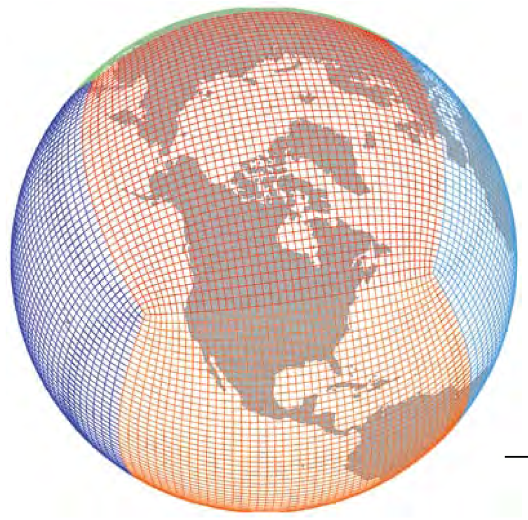

# The Finite-Volume Dynamical Core on the Cubed-Sphere

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## Introduction:

As horizontal resolutions of global climate and numerical weather prediction applications increase beyond the hydrostatic limit of 10-km, the demand for efficient, scalable applications becomes essential. Over the next decade global models will require scalability beyond hundreds of thousands to millions of processors. The current implementation of the finite-volume dynamical core (fvcore), a key component of global models at NASA, NOAA, and NCAR, is limited in terms of scalability by the choice of computational grid (latitude-longitude based). To break through these scalability limitations, the fvcore has been implemented on the quasi-uniform cubed-sphere grid with a 2-dimensional horizontal domain decomposition.

The cubed-sphere fvcore scales well beyond the pure MPI limitations of the lat-lon core displaying ideal scaling on a full node of the SGI Altix (512 CPUs). This improved scalability will allow parent models to scale in excess of tens of thousands of processors as we move toward petascale computing environments.

## Approach:

The quasi-uniform nature of the cubed-sphere grid eliminates the parallelization difficulties associated with the poles. Further, the clustering of grid points at the poles on the lat-lon grid requires special attention to avoid violating the Courant-Friedrichs-Levy (CFL) stability requirements without dramatically reducing the integration time-step. The quasi-uniform nature of the cubed-sphere grid eliminates these problems at the poles. Idealized shallow water and baroclinic experiments are used for scientific evaluation.

## Parallelism:

The cubed-sphere is laid out on the computer as a collection of 6 logically rectangular Cartesian tiles. Each tile can be decomposed in the X- and Y-directions, creating a set of patches which are assigned to multiple processors on a high-performance computing platform.

The software layer known as MPP (Massively Parallel Processing) within the Flexible Modeling Framework at NOAA-GFDL has been used to handle all communication requirements within the cubed-sphere fvcore using MPI as the primary message passing paradigm while easily supporting SHMEM and others on desired platforms.

## Results:

The cubed-sphere fvcore has been evaluated in terms of its computational performance and scientific integrity on the SGI Altix platforms at NASA-GSFC (Explore), NASA-ARC (Columbia), and NOAA-GFDL.

Initial results reveal the cubed-sphere fvcore is producing satisfactory scientific results with computational scalability beyond the lat-lon limitations (Figure 1). At current numerical weather prediction resolutions, ~25-km, the cubed-sphere fvcore scales at an ideal rate within a single 512-CPU node of Columbia, the SGI Altix cluster at ARC's NASA Advanced Supercomputing Division.

It is anticipated that as we push the limits of the hydrostatic approximation, at c720 (12-km) resolution, the cubed-sphere fvcore will scale beyond thousands of processors on Columbia, to tens of thousands to hundreds of thousands of processors on the next generation of high-performance computers.

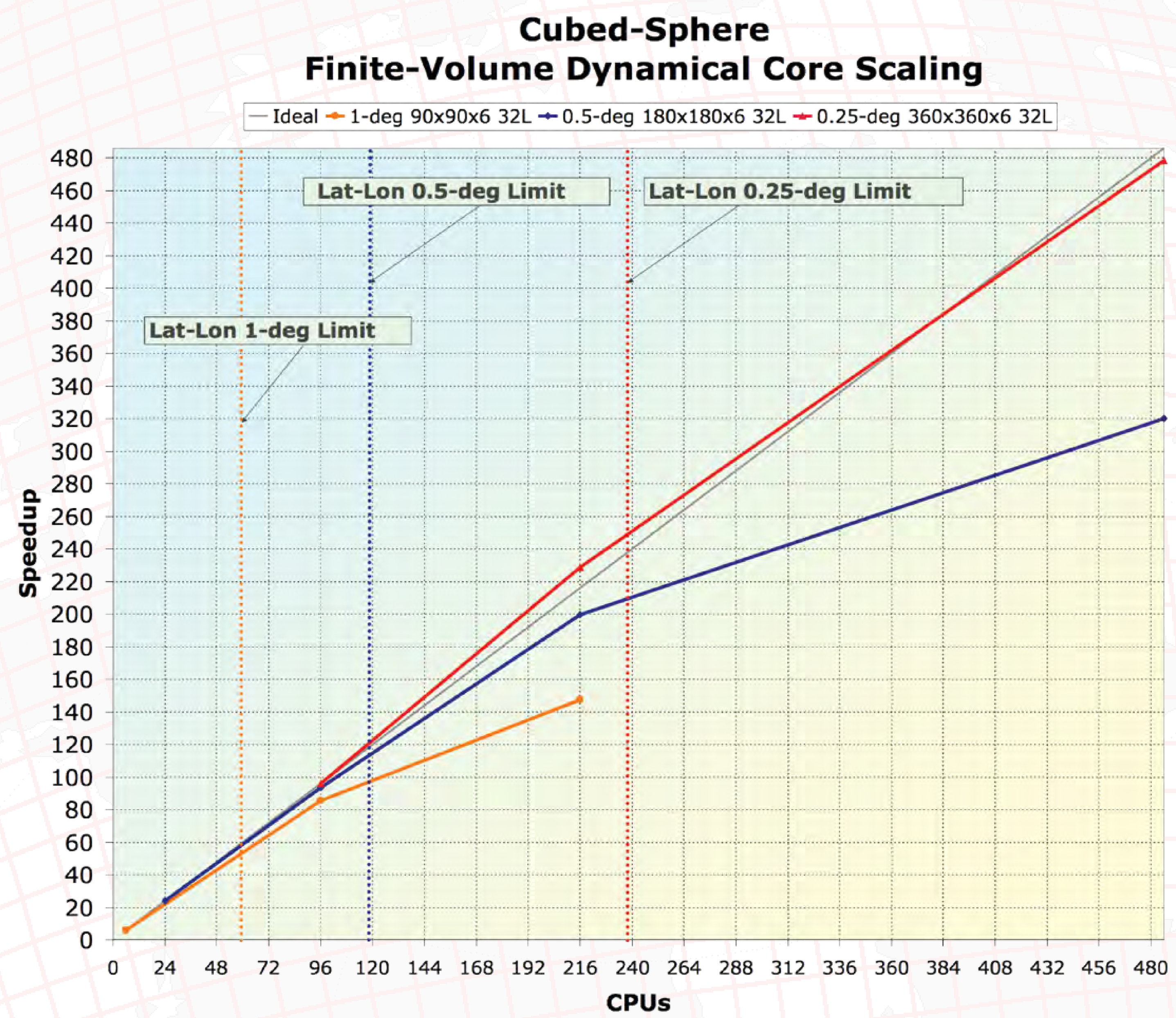


**Figure 1:** Chart of cubed-sphere finite-volume dynamical core (fvcore) scaling and lat-lon limitations on the SGI Altix platform.

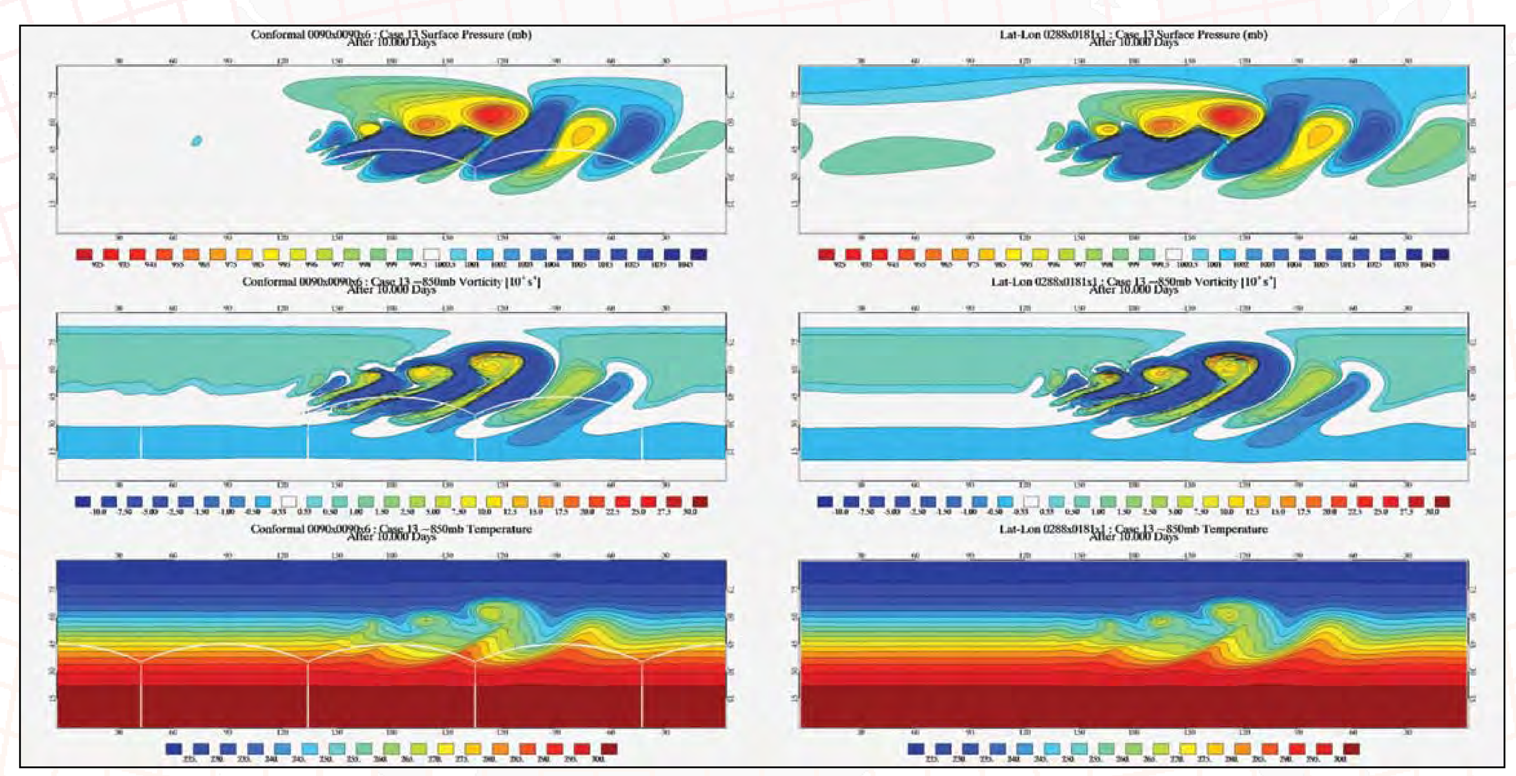

**Figure 2:** Surface pressure and 850 mb vorticity and temperature at day 10 of an idealized baroclinic wave test with the cubed-sphere and lat-lon fvcore at 1-degree (100-km) horizontal resolution.

## Scientific Results:

The cubed-sphere fvcore has been run through the Jablonowski and Williamson baroclinic wave breaking experiment (Jablonowski, C. and D. L. Williamson, 2006). An initial perturbation is introduced in a zonal flow rapidly growing from day 6 onward. Explosive cyclogenesis occurs by day 7, and the baroclinic wave breaks by days 9 and 10 as displayed with excellent agreement at 1-degree resolution for the cubed-sphere and lat-lon grids (Figure 2).

The Held-Suarez test case provides a final validation before full physics implementation. The c44 (2-degree) 32-level grid has been run for 1,200 simulated days with the idealized forcing on Columbia and the statistics have been computed over the final 1,000 days of the simulation. The total simulation time with 150 processors was 1 wall-clock hour. The zonal mean distributions (Figure 3) display excellent agreement with the lat-lon core and those of the original Held-Suarez results. The zonal jet cores are located at about 250 mb and +/- 45-degrees latitude with a magnitude of 30 m/s. The tropopause is present at about 150 mb with a value of 190 K, and a cold surface layer is also observed. The scale of the eddy transports of heat and momentum as well as the variance of the zonal wind and temperature are in line with results observed on the lat-lon grid. All results display an ideal symmetry about the equator. These results provide great confidence in the suitability of the cubed-sphere fvcore for real world climate/weather applications.

Additional Held-Suarez tests with a synthetic moisture forcing simulate humidity and rainfall in an idealized climate simulation. Snapshots for this experiment with real topography from a 12-km (c720) simulation show the distribution of moisture, precipitation, and temperature at the surface (Figure 4).

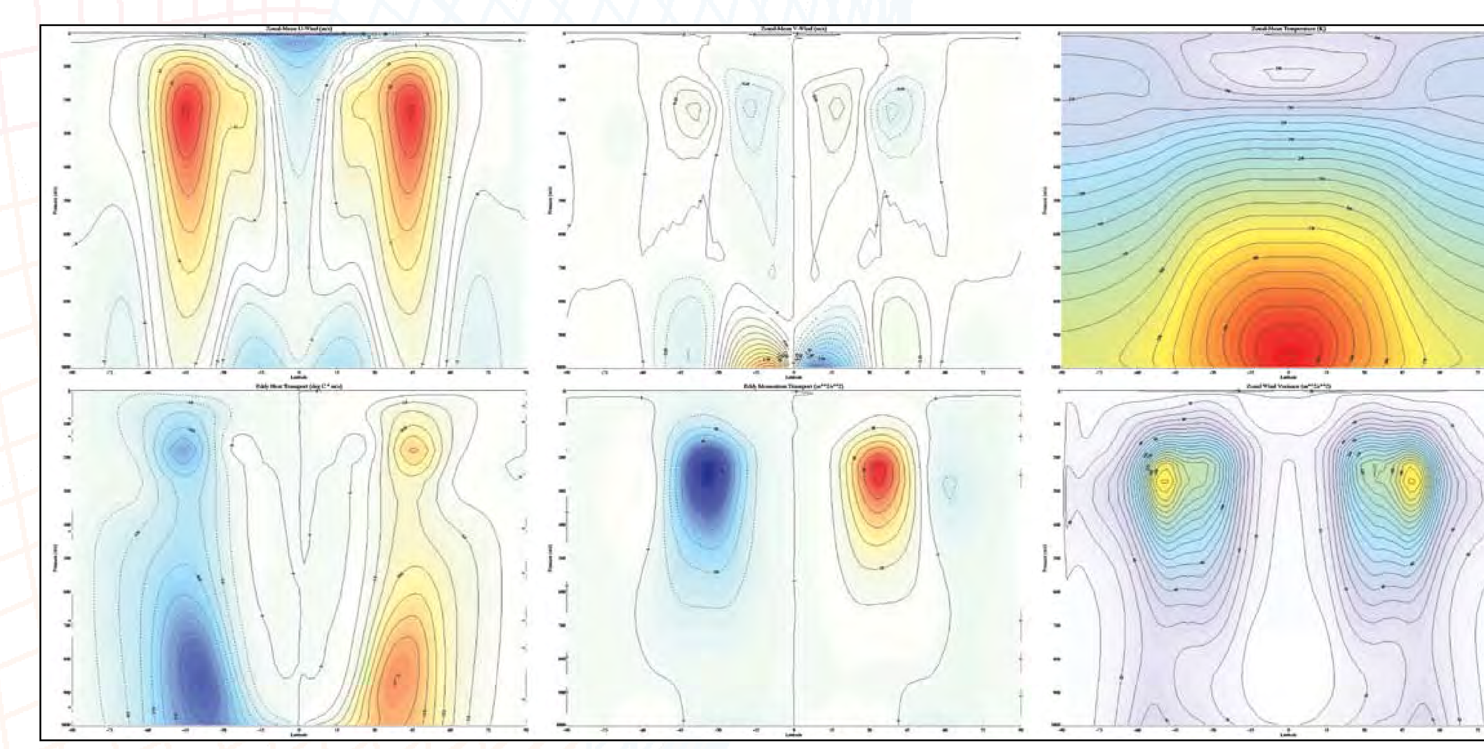

**Figure 3:** 1,000 day zonal mean profiles of zonal and meridional wind, temperature, eddy heat and momentum transport, and zonal wind variance from a c44 Held-Suarez idealized climate forcing experiment.

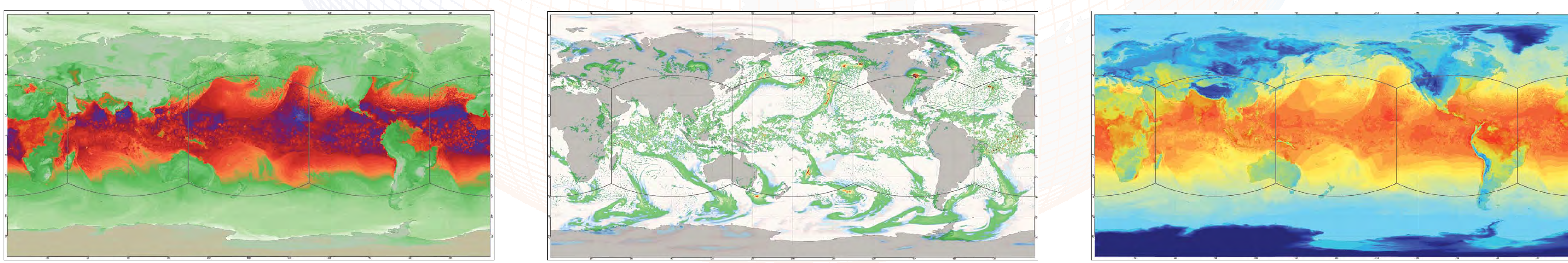

**Figure 4:** Snapshots of surface moisture, precipitation, and temperature from a c720 (12-km) 32-level simulation with idealized temperature and moisture forcing and real topography.